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Preliminary Investigation of Chemical Fundamentals Affecting the Electro-Kinetic Properties of Asphalt-Aggregate Mixtures

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By

Betty A. Behl

Materials Section

Montana State Highway Commission

In Cooperation With The Bureau of Public Roads

April 1963

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ABSTRACT

Investigation and experimentation of a preliminary nature have shown that the adhesive quality of an asphalt-aggregate mixture involves a complex of chemical and electrokinetic fundamentals. The surface contact area for the solid and liquid phases are dependent upon a chemical-electrical linkage in order to adhere. The extent of adhesion is established by: (1) surface reactants initially present on aggregate, (2) behavior of these surface reactants as associated with the liquid medium, (3) hydrogen ion concentration, pH, of the asphalt in effecting surface reactants, (4) surface active groups present in asphalt, and (5) asphalt structure or orientation as a result of its chemical nature. For most effective bonding, it is necessary that all five stated properties are chemically compatible. Left to chance by combination of random materials, achievement of maximum bonding is limited. However, a knowledge of the chemical properties of both aggregate and asphalt and a method of determining same would allow the selection and control of materials in providing chemical compatibility for maximum adhesion.

Research and its application in this area will directly effect the stability and life of bituminous pavements. With a preferred affinity for asphalt, aggregate will not readily strip upon exposure to excessive rain or snow, ground water, or the mechanical abrasion of traffic. Further, pavement failures such as cracking, ravelling, corrugation, etc. may be reduced through the increased plasticity of a stable solid-liquid mixture.

This investigation does not necessarily advocate the use of asphalt additives or other treatments to materials. Rather, it is to demonstrate that a knowledge of the nature of aggregate types and asphalt types will allow the utilization of their present properties to full advantage through selection and control.

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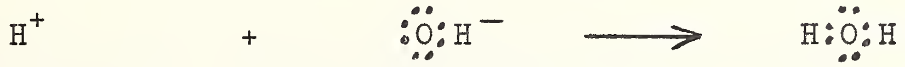
Introduction:

A. Aggregate Surface Charge

The electropositive or electronegative character of aggregate surfaces is relative to the medium which surrounds it. That is, the surface charge on an aggregate may be positive or negative depending upon whether it accepts or donates electrons to the contact medium.

By definition, a Lewis acid is an acceptor of an electron pair and an electron donor is a Lewis base.

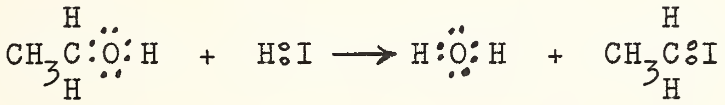


$$H^+ + :\underset{\cdot\cdot}{\overset{\cdot\cdot}{O}}:H^- \longrightarrow H:\underset{\cdot\cdot}{\overset{\cdot\cdot}{O}}:H$$

Lewis acid Lewis base

Neutralization occurs, as in the example, with the combination of an electron acceptor with an electron donor.

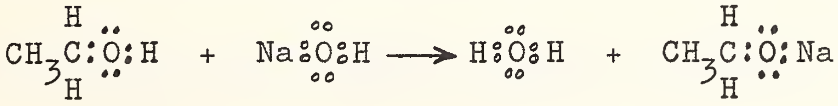
An organic alcohol, such as ethyl alcohol, behaves as a base when in contact with an acid, donating a pair of electrons to achieve neutralization.



$$CH_3\overset{H}{\underset{H}{C}}:\underset{\cdot\cdot}{\overset{\cdot\cdot}{O}}:H + H:I \longrightarrow H:\underset{\cdot\cdot}{\overset{\cdot\cdot}{O}}:H + CH_3\overset{H}{\underset{H}{C}}:I$$

Base Acid

This same alcohol in a solution of a strong base will behave as an acid, acting as an electron acceptor.

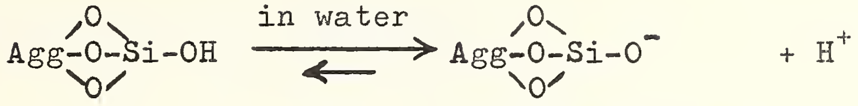


$$CH_3\overset{H}{\underset{H}{C}}:\underset{\cdot\cdot}{\overset{\cdot\cdot}{O}}:H + Na:\underset{\circ\circ}{\overset{\circ\circ}{O}}:H \longrightarrow H:\underset{\circ\circ}{\overset{\circ\circ}{O}}:H + CH_3\overset{H}{\underset{H}{C}}:\underset{\cdot\cdot}{\overset{\cdot\cdot}{O}}:Na$$

Acid Base

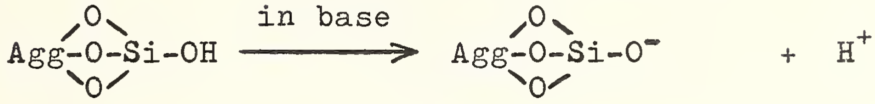
In this same manner, some surface reactants of aggregate may behave as either acids or bases and therefore determine the mechanism of surface reactivity for adhesion.

For example, for a quartzite or acidic type rock:

(1) 

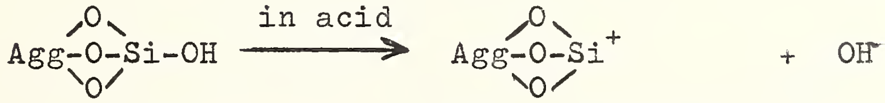
$$\mathrm{Agg{-}\overset{O}{\underset{O}{O}}{-}Si{-}OH} \xrightleftharpoons{\text{in water}} \mathrm{Agg{-}\overset{O}{\underset{O}{O}}{-}Si{-}O^{-}} + \mathrm{H^{+}}$$

Electronegative

(2) 

$$\mathrm{Agg{-}\overset{O}{\underset{O}{O}}{-}Si{-}OH} \xrightarrow{\text{in base}} \mathrm{Agg{-}\overset{O}{\underset{O}{O}}{-}Si{-}O^{-}} + \mathrm{H^{+}}$$

Electronegative

(3) 

$$\mathrm{Agg{-}\overset{O}{\underset{O}{O}}{-}Si{-}OH} \xrightarrow{\text{in acid}} \mathrm{Agg{-}\overset{O}{\underset{O}{O}}{-}Si^{+}} + \mathrm{OH^{-}}$$

Electropositive

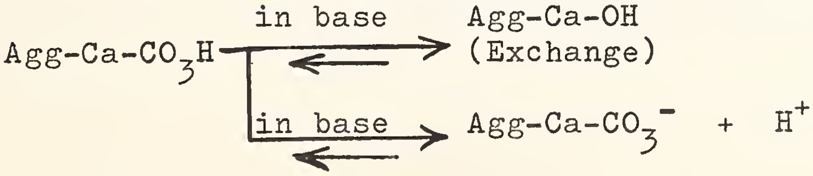
Sample (1), at a neutral pH, has an electronegative surface and would show maximum adhesion with a cationic asphalt or emulsion. Sample (2), at a high pH, has a greater tendency to donate a proton and is therefore more electronegative than sample (1) and would show even greater adhesion with a cationic asphalt or emulsion. Sample (3), at a low pH, has an electropositive surface and would show maximum adhesion with an anionic-type asphalt. The degree of electronegativity or electropositivity on the aggregate surface is dependent upon the ease of ionization of the surface reactants in conjunction with the pH of the medium surrounding them.

For a limestone or basic type sample:

(1) $\mathrm{Agg{-}Ca{-}CO_3H} \xrightleftharpoons{\text{in water}} \mathrm{Agg{-}Ca^{+}} + \mathrm{HCO_3^{-}}$

or

$\mathrm{Agg{-}Ca{-}OH} \xrightleftharpoons{\text{in water}} \mathrm{Agg{-}Ca^{+}} + \mathrm{OH^{-}}$

(2) 

$$\mathrm{Agg{-}Ca{-}CO_3H} \xrightleftharpoons{\text{in base}} \mathrm{Agg{-}Ca{-}OH}\ \text{(Exchange)}$$

$$\mathrm{Agg{-}Ca{-}CO_3H} \xrightleftharpoons{\text{in base}} \mathrm{Agg{-}Ca{-}CO_3^{-}} + \mathrm{H^{+}}$$

(2) or

$$\begin{tikzcd} & \text{Agg-Ca-X (Exchange)} \\ \text{Agg-Ca-OH} \arrow[ur] \arrow[dr] & \\ & \text{Agg-CaO}^{-} + \text{H}^{+} \end{tikzcd}$$

(3) $\text{Agg-Ca-CO}_3\text{H} \xrightarrow{\text{in acid}} \text{Agg-Ca}^{+} + \text{HCO}_3^{-}$

or

$\text{Agg-Ca-OH} \xrightarrow{\text{in acid}} \text{Agg-Ca}^{+} + \text{OH}^{-}$

Sample (1), at a neutral pH, dissociates in water leaving the aggregate surface electropositive and adhesively active with anionic type asphalts. Sample (2), at a high pH, would favor several different reactions: an exchange of basic ions; a common ion effect favoring association; or the dissociation of only a proton rendering the surface electronegative. Sample (3), at a low pH, would favor only an electropositive surface and thereby adhesion to an anionic type asphalt.

Since aggregate samples are usually a combination of acid, basic, or intermediate type rock specimens[1], it is difficult to ascertain which surface charge will predominate and determine the type of asphalt which will insure maximum adhesion. However, a thorough petrographic analysis of the aggregate will reveal the prevailing surface reactant and make possible the selection of a most adhesive asphalt according to corresponding reactive groups.

---

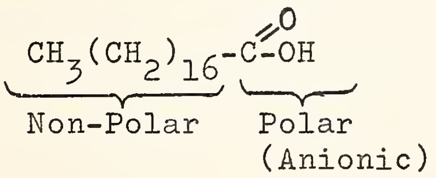
[1] Rock is classified as acidic or basic on the basis of its dissociation in water. Its classification may or may not follow for other mediums.

B. Asphalt Reactivity:

Those polar compounds which occur in asphalt in minor quantities account for the linkages, or micelle type structure, of the asphalt molecules. In addition to contributing to the physical properties and behavior. The reactive groups will vary in number, composition, and polarity depending on the crude source and method of manufacture.

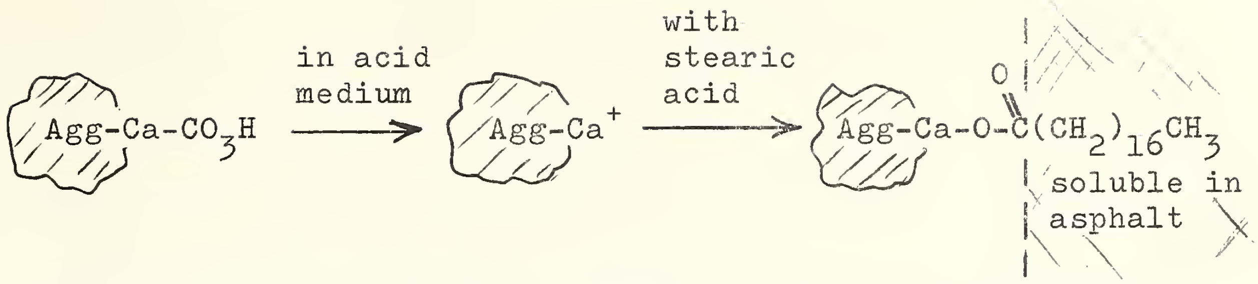
For this reason, only an analysis such as a spectrographic analysis will reveal the over-all acidic or basic nature of the asphalt by quantitatively and qualitatively identifying the reactive groups. There is every indication that the predominating acidic or basic groups contained in an asphalt determine and control the adhesive properties with a specific aggregate. Physical properties are secondary to chemical properties in adhesive effect and are directly related and dependent upon chemical properties.

The polar character of asphalt may be controlled or altered by the addition of a long-chain organic molecule containing a polar end. Stearic acid is such a molecule.



$$\underbrace{CH_3(CH_2)_{16}}_{\text{Non-Polar}}-\underbrace{\overset{O}{\overset{\|}{C}}-OH}_{\text{Polar (Anionic)}}$$

The non-polar portion of the molecule is soluble in asphalt, whereas the polar end will orientate itself toward an opposite polar group such as exists on electropositive aggregate surfaces.



As illustrated, the stearic acid acts as the link between the aggregate surface and asphalt. The acid radical will act as the bonding agent, not only for the normally electropositive aggregates, but for those normally electronegative or acidic ones whose chemical behavior is altered to basic (surface electropositive) when in a more strongly acid medium.

Procedure:

A. Stearic Acid As A Surface Active Agent

Strip tests were performed for six aggregate types using: (a) no surface active agent, (b) Acra as the surface active agent, and (c) stearic acid as the surface active agent.

The following standards in procedure and evaluation were adhered to for the testing:

1. Strip test procedure conformed to that utilized for sample testing in the laboratory; blending of heated asphalt with aggregate, four hours cooling time, twenty-four hours under water, five minutes in Red Devil paint shaker, removal for evaluation.
2. The asphalt for all samples was Farmers MC-5.
3. At least three tests for each type aggregate and treatment were performed and average adhesion determined.

4. A thorough petrographic analysis of each aggregate sample was obtained.

5. Adhesion was evaluated for the samples by three unbiased members of the laboratory. (Note: individual evaluations of percent adhesion did not vary by more than ±5% for any sample or for any group of identical samples.)

The combining of stearic acid with asphalt was readily achieved. The wax-like appearing acid dispersed readily in the asphalt and required little mixing. No odor is detected for stearic acid as in the acra samples. Aggregate with an asphalt-stearic acid coating has a luster different from the glossy black asphalt acra coating. It appears more as a metallic or crystalline luster. The stearic acid used in the testing was obtained from Emery, Fatty Acid Division, as Hyfac 400 Hydrogenated Fatty Acid (65% stearic acid, 35% palmitic acid).

Results:

A. Stearic Acid As A Surface Active Agent

Lab #227257 - Test #1616

Quartzite - 40%

Argillaceous Quartzite - 20%

Argillite - 30%

Greywacke sandstone - 10%

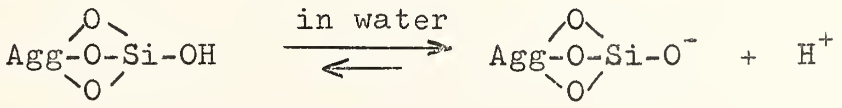
Quartzite - metamorphosed sandstone cemented with silica, much free SiO_2; an acidic rock, also electronegative.

Argillite - metamorphous rock; hard and massive clay (hydrous aluminum silicate with Ca, K, etc.), less free SiO_2 therefore less acidic than quartzite.

Greywacke sandstone - very fine particles of quartz held in a matrix of fine materials, water worn.

In general, the surface reactivity of this aggregate sample might be represented in two groups:

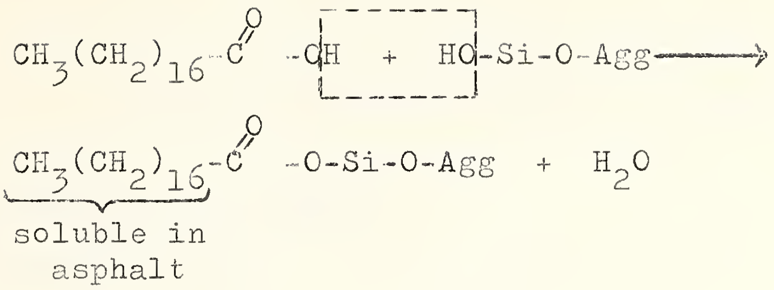
(1) Acidic: Quartzite and Argillaceous quartzite are acidic in nature as a result of high SiO_2 content, 65 to 80%. The acidic behavior might be demonstrated by:



$$\mathrm{Agg{-}O{-}Si{-}OH} \xrightleftharpoons{\text{in water}} \mathrm{Agg{-}O{-}Si{-}O^{-}} + H^{+}$$

The tendency for silica to donate a proton qualifies it as both acidic and electronegative.

Since stearic acid is also a proton donor, the following linkage is established only with difficulty:



$$CH_3(CH_2)_{16}-\overset{O}{\overset{/\!/}{C}}-\boxed{OH \;+\; H}O-Si-O-Agg \longrightarrow$$

$$\underbrace{CH_3(CH_2)_{16}}_{\text{soluble in asphalt}}-\overset{O}{\overset{/\!/}{C}}-O-Si-O-Agg + H_2O$$

It is probable that an (OH^-), rather than a (H^+), is donated by the silica when in contact with stearic acid since stearic acid is more acidic than silica. Then, silica may be regarded as electropositive with respect to stearic acid.

Only moderate adhesion to stearic acid would be expected due to the already acid nature of quartz.

(2) Less acidic: Argillite and Greywacke Sandstone demonstrate less acidity because of a relative decrease in SiO_2 content. There is a decrease in quartz and an increase in ferro-magnesium minerals and some feldspar. Thus, the SiO_2 present is less acidic since its bonding to oxygen has been stretched and weakened by the more electropositive minerals, such as calcium. Therefore, it is expected that an (OH^-) would more readily be given up than in quartzite, and that relatively greater adhesion would occur with stearic acid. However, for the greywacke sandstone, the particles have been extensively water worn which would tend to render the surface less reactive through satisfaction of

surface energies with ions present in the water. The sandstone would then have less available groups to form a chemical linkage to stearic acid.

Lab #226542 - Test #1601

Limestone - 90%

Quartzite - 10%

Limestone - calcite is the chief constituent of limestone rocks causing it to be electropositive. The sample was compact and coarse.

Quartzite - excess SiO_2 and therefore acidic.

The surface reactivity for this sample aggregate could be represented as follows:

(1) Basic: Limestone, after severing and exposure to weather, is of the following general composition:

(a) Agg-Ca-CO_3H

or

(b) Agg-Ca-OH

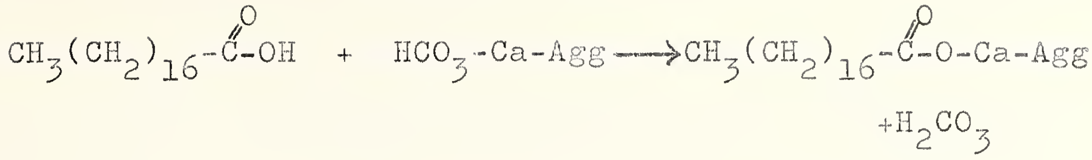
upon further exposure to carbonates in water, the hydroxide in (b) would be exchanged by:

$$\text{Agg-Ca-OH} \xrightarrow{+H_2CO_3} \text{Agg-Ca-}Co_3 + H_2O$$

The tendency for limestone to donate a bicarbonate ion in water renders it electropositive.

$$\text{Agg-Ca-}CO_3H \xrightleftharpoons{\text{in water}} \text{Agg-Ca}^+ + HCO_3^-$$

Chemical bonding of stearic acid with limestone should be readily and easily achieved.



$$CH_3(CH_2)_{16}-\overset{O}{\overset{/\!/}{C}}-OH + HCO_3-Ca-Agg \longrightarrow CH_3(CH_2)_{16}-\overset{O}{\overset{/\!/}{C}}-O-Ca-Agg + H_2CO_3$$

(2) Acidic: Quartzite present in the sample would exhibit only moderate adhesion due to the excess SiO_2.

Lab #227516 - Test #1640

Granite, Porphyritic Granite, Granite Gneiss - 60%

Quartzite - 20%

Shale - 10%

Hornfels - 10%

Granite, Porphyritic Granite, Granite Gneiss: Contains a high percentage of SiO_2, 65 to 80%, some feldspar and a subordinate amount of ferromagnesium minerals. Like quartzite, granite is quite acidic because of its high SiO_2 content; however, the amounts of feldspar and ferromagnesium minerals in the granite types for this sample tend to keep it only moderately acid, as in the argillaceous quartzite sample. Chemical bonding to stearic acid would be expected to be equivalent to that for argillaceous quartzite.

Shale: Clay, quartz and feldspar occurring as a very fine and even-grained rock. These fine particles have been mechanically carried by the water and are for the most part surface inert as a result of the action with the soluble salts in water. Little or no bonding with stearic acid would be expected.

Hornfels: Highly metamorphised silicate rock. The small particles of this sample have been steam and gas altered. Like shale, the surface is quite inert to bonding with stearic acid.

Lab #227840, Test #1672

Vesicular and Glassy Basic Slag - 100%

Vesicular and Glassy Basic Slag: A very basic rock since there is no free SiO_2. As a result of processing, there exists excess quantities of ferro-magnesium silicate and metallic ions. Structurally unstable, basic slag is highly surface reactive and particularly with an acid. Good chemical bonding is to be expected with stearic acid by the displacement of surface anions and formation of a metallic stearate.

Lab #222392, Test #1378

Andesite - 100%

Andesite: The SiO_2 content, between 65 and 52%, of andesite classifies it as intermediate. A sodium plagioclase containing hornblende, arrgite, hypersthene, or biotite; this sample contains a considerable quantity of Ca, Mg, Fe, Al, and K whose surface anions should be readily displaced by stearic acid.

Lab #228305

Sandstone - 100%

Sandstone: A water-worn feldspathic quartzite; consolidated quartz grains cemented together with feldspar. The

chemical composition of feldspar is $M'AlSi_3O_8$ or $M''Al_2Si_2O_8$ in which the metal may be potassium, sodium, or calcium. The cementing material is less acidic with less free SiO_2 and therefore more capable of reaction with stearic acid. For sandstone, the chemical bonding with stearic acid is primarily with the cementing material at the surface.

Table I

Treatment	Aggregate Sample					
	A	B	C	D	E	F
	227257	226542	227516	227840	222392	228305
1.) MC-5 Asphalt	10% Adhesion	35-40% Adhesion	25% Adhesion	90% Adhesion	15% Adhesion	25% Adhesion
2.) MC-5 Asphalt +½% Stearic acid	50% Adhesion	55-60% Adhesion	45% Adhesion	100% Adhesion	90% Adhesion	35% Adhesion
3.) MC-5 Asphalt +1% Stearic acid	65-70% Adhesion	60-65% Adhesion	55% Adhesion	100% Adhesion	100% Adhesion	40% Adhesion
4.) MC-5 Asphalt 1/2% Acra	30% Adhesion	40% Adhesion	35% Adhesion	90% Adhesion	100% Adhesion	85% Adhesion
5.) MC-5 Asphalt 3/4% Acra	45% Adhesion	50% Adhesion	35% Adhesion	95% Adhesion	100% Adhesion	95% Adhesion

Conclusions:

A. Stearic Acid As a Surface Active Agent

In the classification of rocks according to chemical composition, they are referred to as acid, intermediate, or basic, dependent in general upon quantity and combinations of free SiO_2, ferromagnesium minerals, feldspar, olivine, and other minerals. Their theoretical ability, based on probable chemical reaction, for surface reaction with stearic acid might be categorized as follows:

Highly altered, weathered rock; shale, hornels, etc.	- 0%
Acid rock, quartzite, granite, sandstone, etc.	-50%
Acid rock with moderate feldspar; argillite, etc.	-75%
Intermediate; Andesite, diorite, etc.	-100%
Basic; Basic slag, basalt	-100%

Experimental results are in agreement with these values for the individually evaluated components of the samples. In all cases, with the exception of the sandstone sample, adhesion with stearic acid - asphalt equalled or exceeded that with Acra. Acra, being a basic surface active agent, would exhibit greater adhesion than stearic acid with rocks whose acidity exceeds that of stearic acid.

One can also conclude from the samples tested with plain Farmers Mc-5 asphalt, that the asphalt itself was of a mildly acidic nature contributing to the greater adhesion with the basic aggregates limestone and basic slag.

Procedure:

B. pH and Surface Reactivity

The following tables have been compiled to demonstrate the reactivity of aggregate types as corresponding to the pH and available surface active agents of the bituminous material.

Aggregate samples were selected on the basis of their over-all acidic or basic behavior with water, neutral pH. Comparative adhesion was demonstrated for all but acid-anionic medium; chemical reaction occurs with acid and an anionic agent producing an inert precipitate.

Results:

B. pH and Surface Reactivity

Table II illustrates the behavior of basic type aggregate. The surface reactivity in an acid, a basic, or a neutral medium will be most like that of limestone.

Little dissociation of the surface reactants occurs in a basic medium; thus, linkage with any surface active agent is poor although favoring the cationic. In an acid medium, an electropositive surface is favored which would be most reactive with anionic if it were available. Since the aggregate lies somewhere between intermediate and basic, an electropositive surface may be favored, but sufficient electronegative surface allows moderate adhesion with a cationic agent.

Table III illustrates the behavior of acid-type aggregate. The surface reactivity of these samples is expected to follow

most closely that of quartzite.

An electropositive surface predominately exists in an acid medium. If available, an anionic agent would adhere best; however, sufficient electronegative surface charges allow moderate adhesion to cationic surface agents. In a basic medium, a strong electronegative surface is produced which accounts for the best adhesion exhibited with the cationic agent.

Table II

Intermediate to Basic Aggregate

Aggregate Samples	Acid Cationic	Basic Cationic	Basic Anionic
10% quartzite 10% Lime 65% intermediate to basic	80% adhesion	50% adhesion	Very poor adhesion
60% intermediate 15% basic	70% adhesion	40% adhesion	Very poor adhesion
80% intermediate 10% basic 10% acid	70% adhesion	10% adhesion	Very poor adhesion
25% acid 75% intermediate	50% adhesion	30% adhesion	Very poor adhesion
35% acid 55% intermediate 10% basic	20% adhesion	20% adhesion	Very poor adhesion

Table III

Aggregate Samples	Acid Cationic	Basic Cationic	Basic Anionic
85% quartzite-argillite	87% adhesion	94% adhesion	Poor to very poor adhesion
50% quartzite-argillite 15% Granite	91% adhesion	98% adhesion	Poor to very poor adhesion
50% quartzite-argillite 15% granite	85% adhesion	95% adhesion	Poor to very poor adhesion
25% quartzite 50% granite	20% adhesion	75% adhesion	Poor to very poor adhesion
50% quartzite 10% granite 10% argillite	85% adhesion	95% adhesion	Poor to very poor adhesion
35% quartz-quartzite 35% granite 5% argillite	20% adhesion	70% adhesion	Poor to very poor adhesion
70% quartzite 10% granite	50% adhesion	95% adhesion	Poor to very poor adhesion
30% argillite 50% quartzite 5% granite	40% adhesion	98% adhesion	Poor to very poor adhesion

Conclusions:

Although the tables demonstrated the correlation of surface charge, pH, and surface active agent in achieving adhesion with an emulsion; the same principles apply to adhesion with an ordinary asphalt. However, the chemical nature of the asphalt itself is responsible for the pH and for the acidic or basic groups contained therein which may act as the surface active agents. No control or determination of these factors yet exists for asphalt.

Procedure:

C. Infra-red Analysis of Asphalt

Three samples of asphalt were submitted to Connecticut Instrument Company for purposes of determining an effective instrument and method for infra-red analysis.

An attenuated total reflectance, ATR, attachment was utilized with a Beckman 4 infra-red recording spectrophotometer for direct analysis which would eliminate the need of solvent dilution or film sample.

Results:

C. Infra-red Analysis of Asphalt

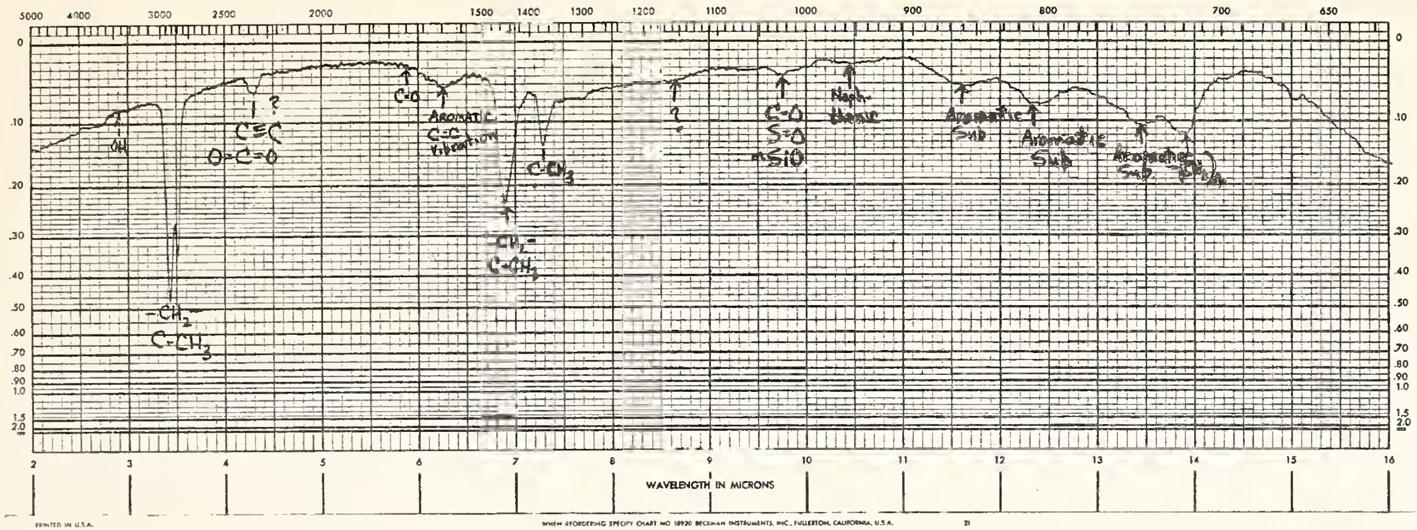
The following spectrographs are for the asphalt samples:

Fig. 1. Diamond; vacuum distilled asphalt

Fig. 2. Conoco; solvent refined asphalt

Fig. 3. Kevin; cracked asphalt

Fig. 1. Diamond,



SPECTRUM NO.

DATE DEC 14 1962

SAMPLE [illegible] (Vacuum Distilled)

SOURCE

STRUCTURE

CONNECTICUT INSTRUMENT COMPANY

ATR

USED FOR STANDARD SAMPLES

ANGLE OF INCIDENCE [illegible] DEGREES

PATH ___ mm

PRISM MATERIAL

SOLVENT

AgCl ___ KRS-5 ___

CONCENTRATION

OTHER

~~SOLID LIQUID SAMPLE HOLDER~~

PHASE

COMMENTS

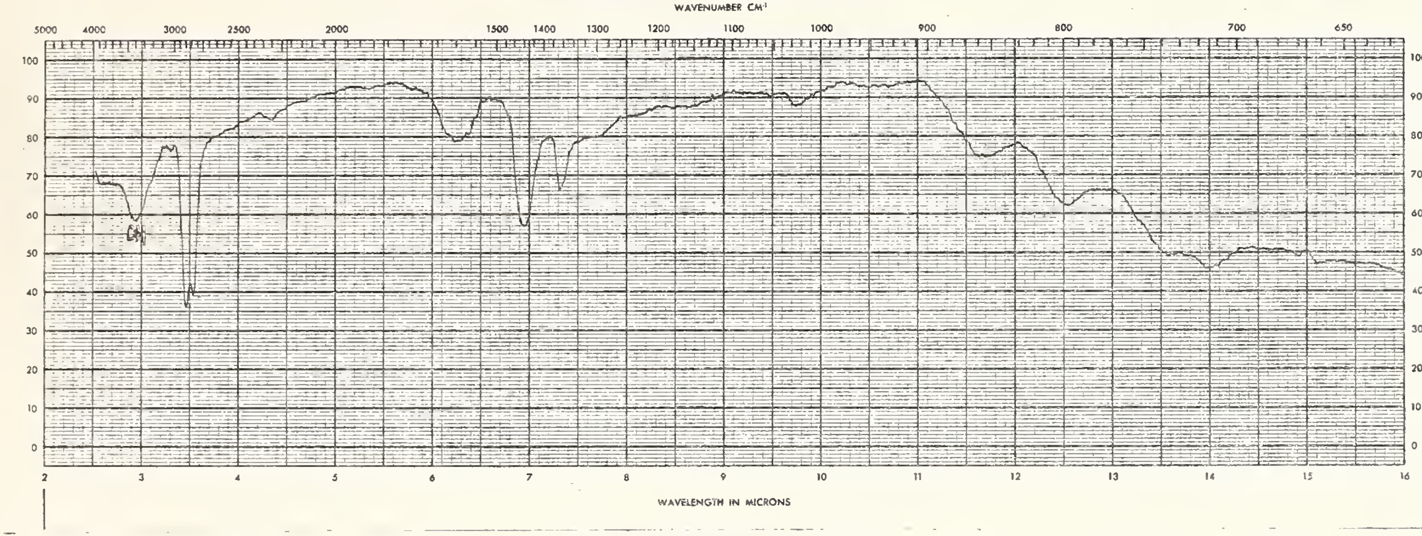
ANALYST

Beckman

INFRARED

SPECTROPHOTOMETER

Fig. 2. Conoco,



SPECTRUM NO.

DATE DEC 14 1962

SAMPLE [illegible] (Solvent Extracted)

SOURCE

STRUCTURE

CONNECTICUT INSTRUMENT COMPANY

ATR

USED FOR STANDARD SAMPLES

ANGLE OF INCIDENCE 65 DEGREES

PATH ___ mm

PRISM MATERIAL

SOLVENT

AgCl ___ KRS-5 ___

CONCENTRATION

OTHER AgCl PRESSED PLATE

SOLID LIQUID SAMPLE HOLDER

PHASE

COMMENTS

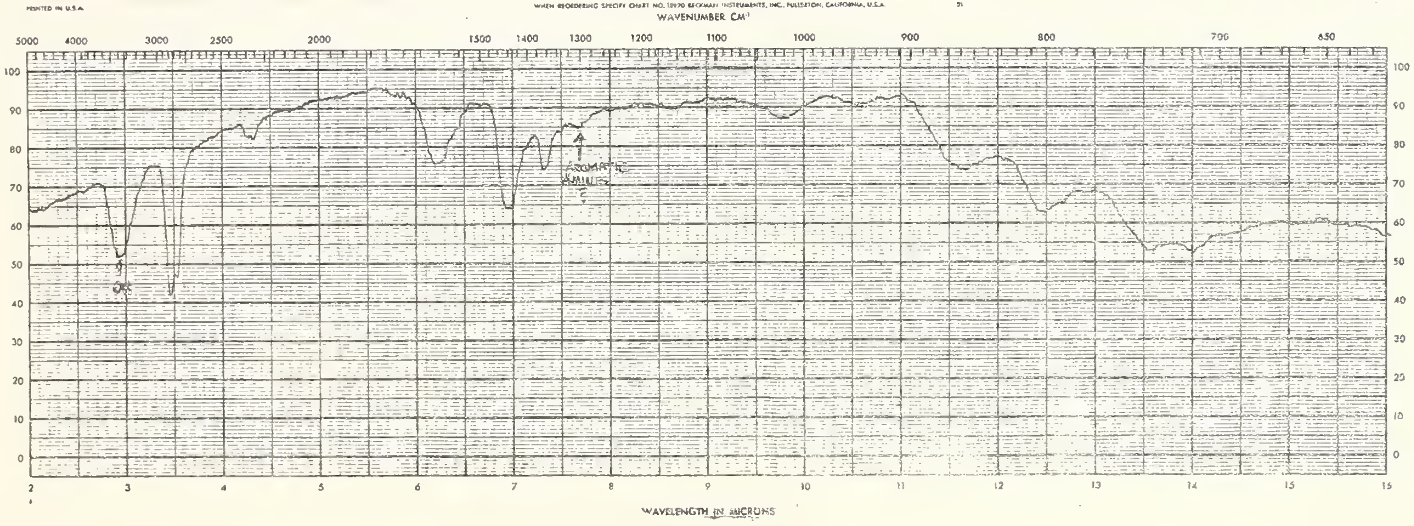
ANALYST

Beckman

INFRARED

SPECTROPHOTOMETER

Fig. 3, Kevin



SPECTRUM NO.

DATE DEC 13 1962

SAMPLE [illegible] (Cracked)

SOURCE

STRUCTURE

CONNECTICUT INSTRUMENT COMPANY

ATR

USED FOR STANDARD SAMPLES

ANGLE OF INCIDENCE 65 DEGREES

PATH ___ mm

PRISM MATERIAL

SOLVENT

AgCl ___ KRS-5 ___

CONCENTRATION

OTHER AgCl PRESSED PLATE

SOLID LIQUID SAMPLE HOLDER

PHASE

COMMENTS

ANALYST

Beckman

INFRARED

SPECTROPHOTOMETER

Conclusions:

C. Infra-red Analysis of Asphalt

Some of the important groups of asphalt have been identified according to the wave length of absorption peaks. Thus, a method has been established for the quantitative and qualitative analysis of asphalt samples. It can be noted from the spectrographs that a similarity of groups exists for the Conoco and the Kevin asphalt samples. The following observations might be made of the samples:

Diamond: Few (OH) groups, lesser aromatic vibrations and aromatic substitution. One would therefore expect this asphalt to be less basic or tend to the acidic as compared to the other two samples.

Conoco: Higher (OH) concentration, higher concentration of aromatic substitutions and aromatic vibrations. The groups of this asphalt indicate a more basic behavior.

Kevin: Greatest (OH) concentration, but lesser aromatic substitutions as compared to Conoco; possibly tending to higher basicity.

The observations thus far made are general ones. A thorough analysis and knowledge of interpretation of the spectrographs would reveal the linkages and actual structure of the asphalt. The physical properties and the adhesive qualities of asphalt are dependent upon its chemical nature and structure. It therefore appears imperative that the chemical properties

of asphalt be studied if its influence as the medium for aggregate is to be known. As has been demonstrated, the surface reactivity of aggregate depends upon the medium associated with it. It is evident from the three spectrographs that their constituents and amounts of asphalt types are very different although the physical measurements of viscosity, ductility, etc., may be identical.

Since the adhesive qualities with the same aggregate are not identical for asphalts of similar physical properties, it is reasonable to assume that the difference in chemical nature is responsible. The acidic and basic groups, the linking elements, the degree of saturation, and the micelle-type structure of the asphalt play an exceptionally important role in the electro-potential of the double layer at the asphalt-aggregate surface contact and thereby the adhesive effects. Heretofore, little or no emphasis has been placed on the fundamental chemical structure and behavior of asphalt. If maximum adhesion for bituminous materials is to be realized, the utilization of infra-red spectra, its analysis and interpretation, would serve as one of the simplest and most thorough means of asphalt study.